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Plasma Channel Dynamics Created by High-Current Relativistic Electron Beam When Being Distributed in Gaseous Media of Various Types

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Experimental results of determination of plasma channel dynamics created by high-current beam (energy of electrons $E_e = 1,1\cdot10^6$ eV, beam current $I_b=2,4\cdot10^4$ A, with pulse duration $t=60\cdot10^{-9}$c.) in gases: helium (He), nitrogen (N_2), neon (Ne), Air (Air),argon (Ar), krypton (Kr), xenon (Xe),humid air (Air:H_2O) at pressure from 1 to 760 Tor are presented. It is showed that in gases with low value relation of collision rate v to ionization rate u_i ($v/u_i<1$) electron beam forms wide plasma channel of high conductivity: $R_b/R_p<1$, (where R_b- beam radius, R_p- plasma channel radius), which provides suppression of large-scale resistive hose instability (RHI).

1. Introduction

Great interest towards applied utilization of high-current relativistic electron beams (REB) interacting with various gaseous media is predetermined not only by their unique capacity for transportation of energy of high density through gas, but also by possibility of realization of a number of selective plasma chemical reactions or synthesis of compounds in beam plasma [1]. Immediate research of REB distribution dynamics in various gaseous media can give a full idea about development and effect of large-scale instabilities among which the dominant is: resistive hose instability (RHI) [2]. The results of this research can built the basis for RHI suppression or stabilization methods being worked out.

2. Experimental technique

Research was done at accelerator «Tonus» [3] generating high-current REB with the following parameters: electron energy $E_e = 1,1\cdot10^6$eV, beam current $I_b=(2,0\text{-}2,4)\cdot10^4$ A, pulse duration $t=60\cdot10^{-9}$c. Electron beam with a diameter at accelerator outlet of $\sim5\cdot10^{-2}$ m, was injected through anodic titanic foil $50\cdot10^{-6}$m. thick, to metal drift tunnel (DT) with a diameter of $9,2\cdot10^{-2}$ m, and being filled up with one of the gases mentioned above at pressure from 1 to 760 Tor. In order to determine plasma channel dynamics created by heavy-current REB in various gaseous media previously used equipment and technique for radial conductivity profile measurements was utilized [4].

3. Results and discussion

Radial conductivity profile of plasma channel created by REB in gases (at pressure P = 300 Tor) and its time dynamics are displayed at Fig. 1. Formed by heavy-current REB, homogeneous wide plasma channel R_b / R_p <1, (where R_b- beam radius, R_p- plasma channel radius) of high conductivity in Ne, Ar, Kr, Xe with characteristic maximum at beam periphery testifies for past gas electrical break-down in radial direction. This provides REB steady distribution and dampening its transverse vibrations throughout the whole distribution length. At the same time, for gases He, Air, N_2, Air : H_2O, with the increase of pressure P radial conductivity profile tends to $R_p=R_b$ and experiences synchronous vibrations corresponding to REB displacement relative to distribution axis thus decreasing its effectiveness essentially. Differences obtained in conductivity profiles of plasma channels can be explained with the help of distinctions of gas and kinetic parameters of the gases used.

After full REB space charge neutralization is reached, secondary electrons do not leave beam anymore and take part in ionization process, accelerating in induced longitudinal electrical field E_z. Appearance of induced field E_z is conditioned by rate of beam current change I_b and is proportional to ~ L dI/dt, where L - inductance of system. This field induces plasma current I_p flowing inside the beam and by its field compensating REB magnetic field. Electrons accelerated in induced field and reaching the energy of keV, form electron avalanche.

Process of electrical break-down has strongly pronounced threshold character. Existence of such a threshold is connected with strong dependence of atoms ionization rate by electron impact u_i, from the value of electrical field and also with the fact that besides ionization there are mechanisms which prevent avalanche from development. In work [5] by the example of numerical model it was shown that for gases in which relationship of collision rate v to ionization rate u_i is relatively small, i.e. ($v/u_i<1$) formation of wide (R_b/R_p <1) plasma channel is the most possible. The results which we obtained for gases: Ar , Ne , Kr , Xe can serve as experimental confirmation to this numerical model. Of course, one of the most important addition to the mechanism of plasma channel formation described above is taking into account radial constituent of electrical field determined from the condition: $E(r) = U/r \ln(r_2/r_1)$, where U-voltage (V), r_2–drift tunnel radius, r_1- beam radius. Value estimation E (r) gives the order of magnitude~10^5-10^6 kV/sm. In [6] it was demonstrated that in this case radial electrical field is displaced to beam periphery in charge neutralization process. At the same time amplitude maximum of electrical field $E = (E_z^2+E_r^2)^{1/2}$ moved to the "wings" of the beam and avalanche multiplication of electrons lead to formation

of conductive channel wrapping beam, essentially decelerating development of resistive hose instability (Fig.2.) It is break-down in the radial direction that forms maximum of radial conductivity profile at the edge of REB (gases: Ar, Ne, Kr, Xe).

4. References

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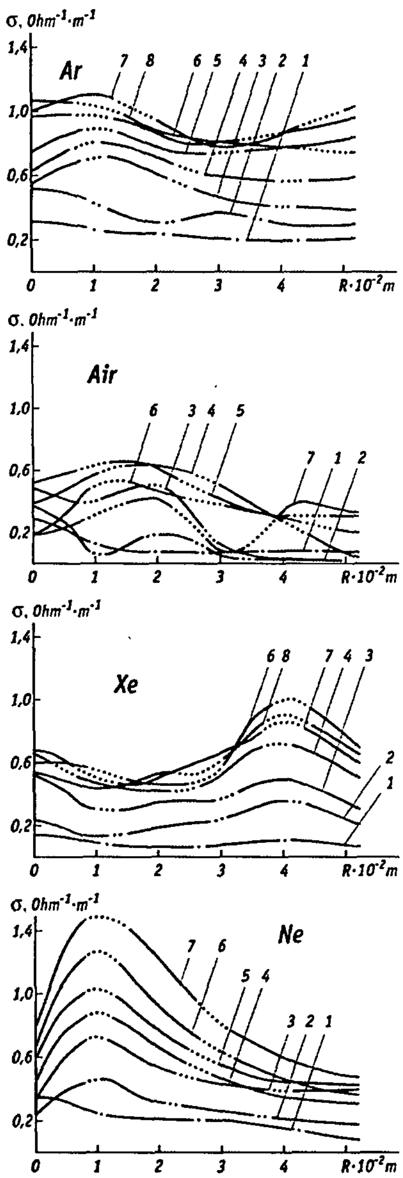

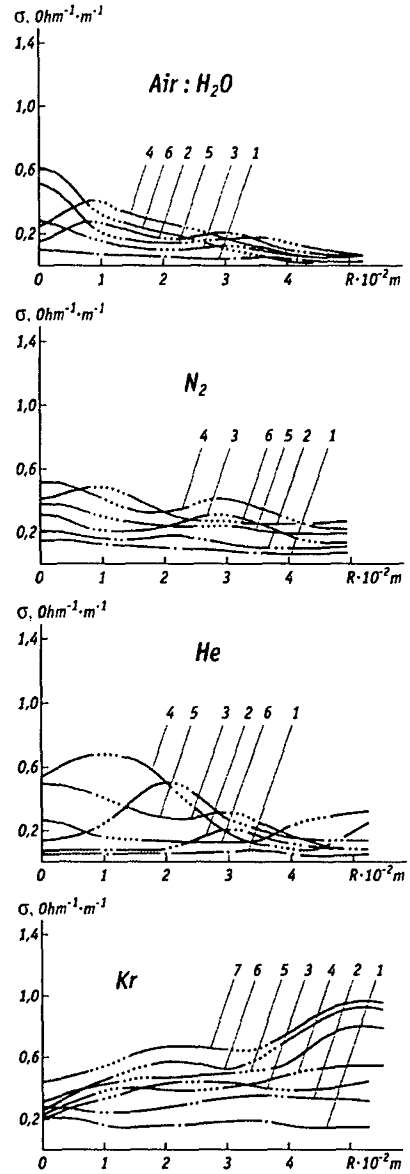

Fig.1. Radial conductivity profile of plasma channel created by REB in gases (at pressure P = 300 Tor.). The time elapsed from the beginning of a pulse: 1- 10 ns., 2- 20 ns, 3 - 30 ns., 4 - 40 ns., 5- 50 ns., 6- 60 ns., 7- 70 ns., 8- 80 ns.

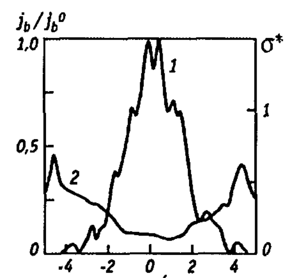

Fig.2. Formation of conductive (σ*)(2) channel wrapping beam j_b(1). Ref. [6].